NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a progress report at least every three months during the project duration. Reports are due the 5th of the month following the end of the quarter. Please provide a project update even if no work was done during this reporting period.

Project # 26962G	**Report Period** Year: 2018 X Q1 (Jan-Mar) ☐ Q2 (Apr-Jun) ☐ Q3 (Jul-Sep) ☐ Q4 (Oct-Dec)	
Project Title: The Living Bridge: A Benchmark for Bridge Monitoring The Living Bridge: Tidal Turbine Deployment System		
Project Investigator: Erin S. Bell Project Co-Investigators: Martin Wosnik, Kenneth Baldwin **Phone: (603)862-3850** **E-mail: erin.bell@unh.edu**		
Research Start Date: sample July 1, 2016	**Research End Date:** September 30, 2018	**Project schedule status:** ☐ On schedule ☐ Ahead of schedule X Behind schedule

Brief Project Description:

This project is a collaborative project between the civil and environmental engineering, mechanical and ocean engineering programs at UNH, the NHDOT and several industrial partners to install of an array of structural health monitoring, environmental and estuarine sensors on the Memorial Bridge in Portsmouth, New Hampshire that will be powered by a tidal turbine attached to one of the bridge piers. The funding for the Tidal Turbine Deployment System is leveraged with funding provided by the National Science Foundation's Partnerships for Innovation (PFI) Program, The Living Bridge: The Future of Smart, Sustainable User-Centered Transportation Infrastructure.

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

Benchmark for Bridge Monitoring:
The final instrumentation plan for the structural health monitoring was discussed at the June 28th 2016 technical advisory group meeting in Concord, NH, and was approved on July 18 2016. The structural sensors were installed on the bridge structure in March 2017. The installation was complete on March 8 2017. The sensors are operational. The marine sensors are installed on the turbine support platform and the collected data is integrated with the structural information, mechanical performance information and environmental information. The structural sensors on the vertical guide posts were installed in late October 2017. These sensors are not connected to the database continuously and will not be connected until the droop cable is installed with the tidal turbine in March/April 2018.

A pseudo-static load test was conducted on October 27th 2017. This load test used a NHDOT truck loaded with concrete barriers. The test location was the Portsmouth side of the bridge. A NHDOT truck carrying Jersey barriers was used. A total of five runs (5 mph) were conducted: three (3) runs on the northbound side and two runs on the southbound side. Each static run included two stops. In addition, five dynamic runs (15-30 mph) were conducted: two runs without traffic (one on the northbound side and one on the southbound side) and three runs with traffic (two on the northbound side and one on the southbound side). This collected data is being used to validate the multi-scale structural models of the Memorial Bridge.

A set of full-scale and multi-scale models of the bridge and connection was developed at UNH in Lusas®. This program was chosen to mirror the modeling done during bridge design by HNTB. A comparison of Lusas® models with the SAP® model is shown that they are in good agreement with each other in preparation for calibration with collected field data from the October 2017 load test.

The structural model of the Memorial Bridge in SAP2000® is complete. This model is for the Portsmouth span and lift tower only. This model is being validated with respect to the collected data specifically focusing on stiffness of the connection elements.

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A detailed model of the gusset-less truss connection in ABAQUS® is completed. The response from this model is the basis for a quantitative set of stiffness values (stiffness matrix) to represent the connection in the structural SAP® model. This model was manually verified with respect to the collected data and the analytical responses from this model will be to determine the stiffness value of the super-element that will represent the gusset-less connection in the SAP2000® model.

Graduate student, Timothy Nash, conducted a study of wind loads developed from AASHTO, ASCE7-10 and European codes to predict the structural response of the lift tower. Tim defended his thesis and graduated with his masters degree in December 2016. In May 2018, Timothy will present part of his results in the Engineering Mechanics Institute (EMI) conference in Boston, MA. A journal paper on this work will be submitted in April 2018. This predicted information will be compared to the measured structural response of the tower, as a data set is collected over time under varying environmental conditions.

Graduate student, Chao Yang, conducted a probability-based environmental demand assessment of the wind and wave loads on the tidal turbine deployment platform, specifically with respect to the anchorage capacity. Chao defended his thesis and graduate with his masters' degree in December 2017. In May 2018, Chao will present part of his results in the Engineering Mechanics Institute (EMI) conference in Boston, MA. A journal paper is planned for submission in May 2018.

PI Bell continues to communicate with bridge designer, Ted Zoli, both in live and virtual meetings. The last conference call as held on April 14th 2017 with Professor Ricardo Medina to discuss this project and program 26962M. The most recent meeting was a live meeting in New York on November 22nd 2017.

In the last three months, PhD candidate, Maryam Mashyekhizadeh, started cooperating, as an intern, with Bridge Diagnostics, Inc. (BDI) at their office in Colorado. She was mainly involved in monitoring the data collection process and troubleshooting issues associated with the collected data. In addition, she developed a trigger protocol, in collaborating with postdoctoral research scholar Vahid Shahsavari, to trigger capturing a high-speed data during lift operations. This would help to have more oriented data collection to capture the data which is more essential for further condition assessments. Figure 1 shows a typical response of accelerometers during lift operating condition.

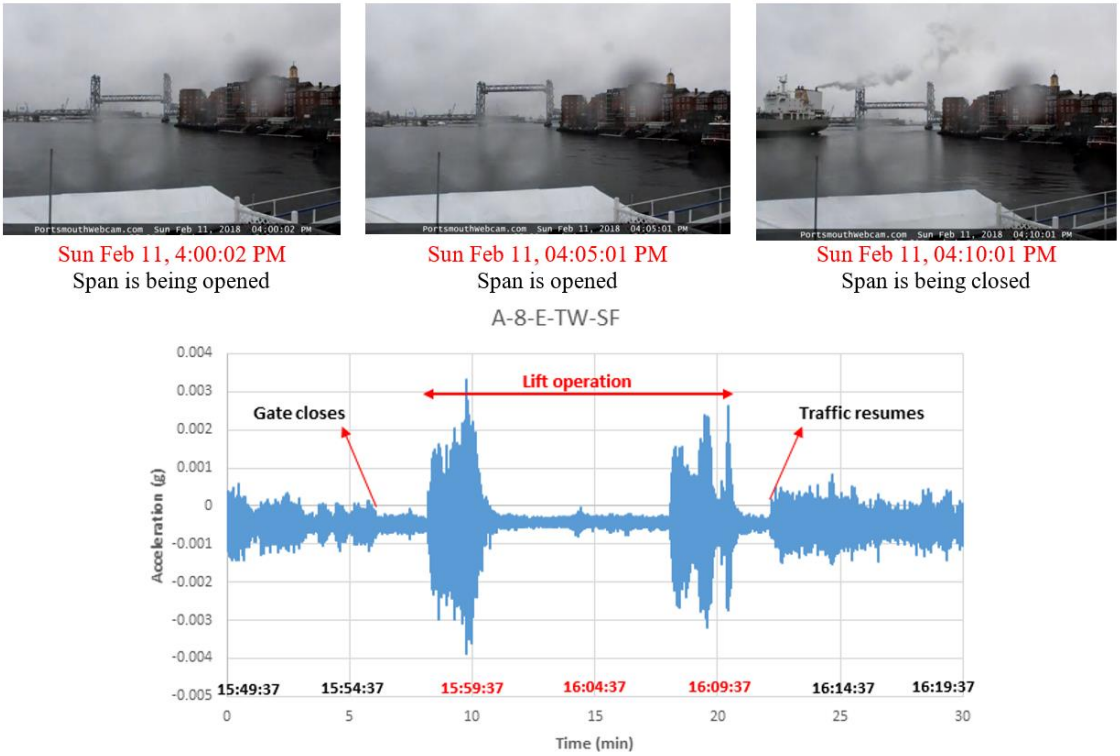

Figure 1: Acceleration response during lift event at the bridge.

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Progress of model updating, parameter estimation and condition assessment of the Memorial Bridge;
PhD candidate, Milad Mehrkash, developed an API MATLAB-based code for updating the SAP2000 model of the Memorial Bridge. Debugging the code is being finalized. This computer program is now able to estimate the stiffness parameters of small scale structural models. The program needs to be promoted for analysis of large scale structures.

PhD candidate, Maryam Mashayekhizadeh, finalized the multi-scale global model of the Memorial to reduce efficiently the time of analysis. In this model, the less stressed elements are modeled with beam elements to show the global performance of the bridge while gusset-less connection, which are higher stressed and the performance of each under multiple loads is a matter of concern, are modeled with shell elements. See Figure 3 the multi-scale model of the bridge.

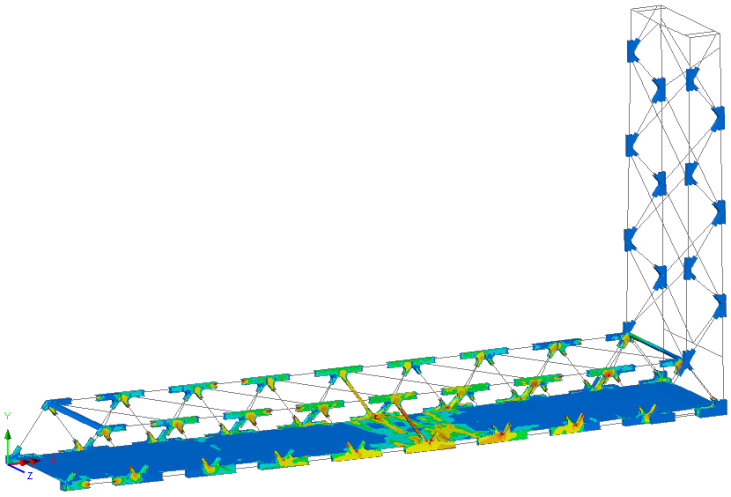

Figure 2: Multi-scale finite element model of the bridge to efficiently analyze the behavior of the bridge.

In March 2018, Maryam did a presentation at the 27th ASNT Research Symposium in Orlando, FL, on “Influence of temperature on vibration-based structural health monitoring of a vertical bridge”. The vibration data of 4-5 months are collected to investigate the influence of environmental variations, including temperature, wind and humidity, as well as the interaction of each two parameters on the acceleration response of a multiple accelerometers installed at the bridge. In addition, a pattern recognition algorithm is provided to be able to predict the vibration response of each sensor (See figure 3). The algorithm is expandable for long-term condition assessment of the bridge. It is planned to further investigate the influence of lift operation interacting with other influential factors on the performance of the bridge.

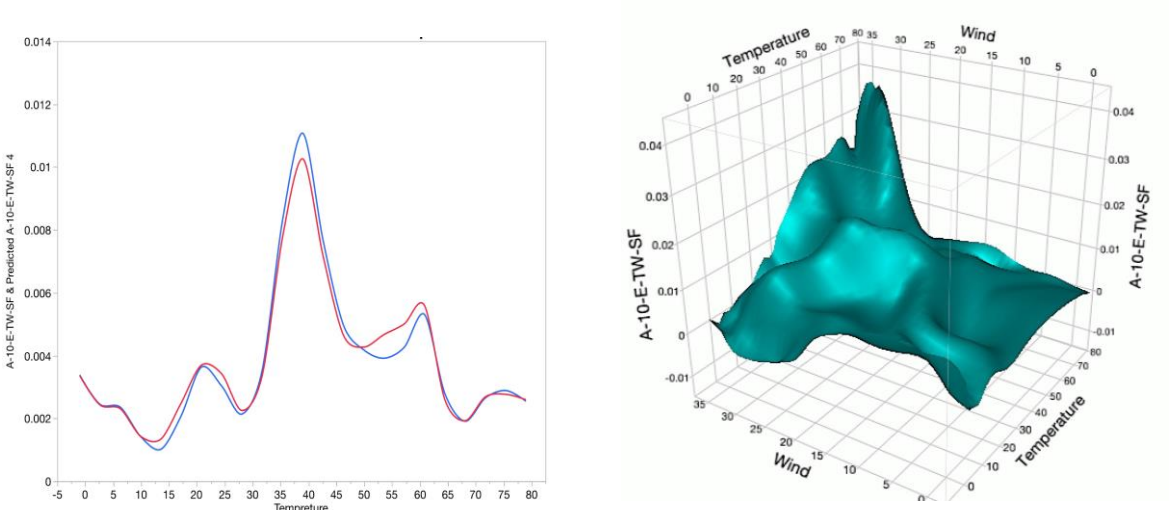

Figure 3: Studying the influence of environmental variations on vibration data.

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Postdoctoral research scholar, Vahid Shahsavari, developed an objective decision-making protocol for future condition assessment of the Memorial Bridge. The focus of this research is on long-term monitoring of the bridge behavior to train a baseline model in the early age of the bridge when the condition is undamaged. In January 2018, Vahid presented the preliminary results of his findings at the 97th Annual Meeting of Transportation Research Board (TRB), Washington D.C. The proof of concept is analytically verified to detect the change in structural performance due to abnormal events using finite element model of the Memorial Bridge in SAP2000®, resulting in a conference paper at the 27th American Society for Nondestructive Testing (ASNT) Research Symposium, Orlando, FL, presented by Vahid.

List of submissions and presentations:

- Milad Mehrkash and Erin Santini-Bell, "Modeling and Characterization of Complicated Connections in Structural and Mechanical Systems as Applied to a Gusset-less truss connection", 97th Annual Meeting of Transportation Research Board (TRB), Washington D.C, 2018.
- Maryam Mashayekhizdeh and Erin Santini-Bell, "Influence of temperature on vibration-based structural health monitoring of a vertical bridge", 27th ASNT Research Symposium, Orlando, FL, 2018.
- Vahid Shahsavari, Milad Mehrkash and Erin Santini-Bell, "Structural Health Monitoring of a Vertical Lift Bridge Using Vibration Data", 27th ASNT Research Symposium, Orlando, FL, 2018.
- Milad Mehrkash, Vahid Shahsavari and Erin Santini-Bell, "Instrumentation Sufficiency of a Vertical Lift Bridge for Modal System Identification by Frequency Domain Analysis", Engineering Mechanics Institute Conference, Boston, MA, 2018.
- Timothy Nash, Erin Santini-Bell, Milad Mehrkash and Vahid Shahsavari, "An Objective Decision Making Protocol for Lift Bridge Operation Subjected to High Wind Loads", Engineering Mechanics Institute Conference, Boston, MA, 2018.
- Chao Yang, Erin Santini-Bell, Vahid Shahsavari and Milad Mehrkash, "Probability-Based Demand Evaluation of the Bridge Tidal Turbine Deployment System Subject to Environmental Events", Engineering Mechanics Institute Conference, Boston, MA, 2018.
- Vahid Shahsavari, "Long-Term Monitoring of Bridges under Operational and Environmental Variations", The Transportation Research Board (TRB) 97th Annual Meeting, Washington, D.C., January 7-11, 2018.
- Maryam Mashayekhizadeh, Milad Mehrkhash, Vahid Shahsavari, Erin Bell, "Multi-Scale Finite Element Model Development for Condition Assessment of Vertical Lift Bridge", ASCE Structures Congress 2018, Fort Worth, TX, April 19-21, 2018.

Tidal Turbine Deployment System

The tidal turbine deployment system consists of vertical guide posts (VGPs) and a turbine deployment platform (TDP) on which the tidal turbine will be installed.

The VGP installation by Pepperell Cove Marine was completed on 13 December 2016. The TDP was first test-deployed at the bridge for one tidal cycle on 31 March 2017 (spring flood tide). After modifications to the pile guide system and installation of the marine instrumentation the TDP was redeployed at the Memorial Bridge on 22 June 2017 by marine contractors Pepperell Cove Marine.

After the redeployment of the TDP UNH personnel remained on the platform for a tidal cycle, followed by in-person inspection during peak currents for each tidal cycle. The UNH team has continued to perform in-person inspection and maintenance on the instrumentation and TDP, arriving by boat from the UNH Pier in New Castle, NH. After the close monitoring during the initial deployment period, the inspection and maintenance trips were conducted twice per week. After observing the TDP in operation for some time and after a webcam was installed at Portsmouth Harbor Cruises to monitor the TDP, the team felt comfortable to reduce the inspection and maintenance trips to once per week.
Over the course of the summer the marine instrumentation has been collecting data. The instrumentation on the TDP is believed to already have created some of the longest datasets of their kind for these research purposes in the estuary.

Electrical conduit and cables have been run to the pier cap of Pier No. 2 by project partner Northeast Integration (NEI). These cables will be run out to a droop under the bridge deck which will serve as the data and power connection to the TDP.

The TDP was removed from the bridge on 8 November 2017 for the installation of the Turbine Pitching Mechanism (TPM).

The TPM was designed to support the tidal turbine and deploy it through the TDP moon pool. The first part of the TPM was installed on the TDP in December 2017, and the final parts of the TPM were installed in February 2018, by Pepperrell Cove Marine.

UNH has been working closely with the new turbine provider, New Energy Corporation of Calgary, AB, Canada. We have had weekly conference calls with New Energy engineers, to discuss integration of the New Energy Turbine into the UNH-designed deployment system and to monitor procurement and fabrication progress. The graduate student most involved with the design of the TDP and TPM, Ian Gagnon, spent a total of four weeks in Calgary working with New Energy (under funding of the NSF INTERN program). There have been some minor delays, but turbine fabrication is almost complete, and we expect shipment of the turbine to the UNH Pier by the end of April 2018.

The platform is presently at the UNH research pier. It will be redeployed at the bridge site after the tidal turbine from New Energy Corporation is added, likely towards the end of April 2018. The turbine will be using a UL1741 certified inverter (similar to what solar photovoltaic systems use) and Northeast Integration has been in coordination with New Energy to ensure that the turbine will work well with the bridge electrical system. The bridge owner, NH DoT, needs to ask Eversource to install a power meter that can run in reverse, should the tidal turbine ever produce more power than the bridge and instrumentation can use. The power output of the turbine (<10 kW) would not significantly affect the power provided by the utility, as its peak power is smaller than some residential solar photovoltaic systems. Eversource (Distributed Generation Manager Richard Labrecque) is supportive of the Living Bridge project turbine connecting to the bridge grid.

The Living Bridge

In August graduate students Ian Gagnon and Kaelin Chancey presented on the Living Bridge Project at the 2017 European International Network on Offshore Renewable Energy (INORE) Symposium at The Burren, Co. Clare, Ireland. Kaelin Chancey was awarded the best presentation at the symposium.

Graduate students Ian Gagnon and Kaelin Chancey with summer interns Mallory Cashman and Ian Wilson shot video for a video to be created by the NH Marine docents which highlights work being done on the turbine deployment platform.

PI Bell presented the Living Bridge Project to the faculty at the University of Johannesburg-Auckland, South Africa during an outreach trip in July 2017.

PI Bell presented the Living Bridge Project at the Co-PI athe 12th International Conference on Structural Safety and Reliability in Vienna, Austria on August 6-10, 2017.

Bell, E., Mashayekhizadeh, M. Adams, T. and Nash, T. (2017). “Structural Monitoring to Support Decision-Making a Vertical Lift Bridge”, ICOSAAR, Vienna, August 6-10.

In September 2017, postdoctoral research scholar Vahid Shahsavari presented the Living Bridge Project at Northeast Bridge Preservation Partnership (NEBPP) Annual Meeting in New Brunswick, NJ.

Erin Bell and Martin Wosnik presented at the New Hampshire Engineer Week in Concord in February 2018:
Bell E; Wosnik M, “The Living Bridge: Smart Infrastructure Powered by Tidal Energy”, New Hampshire Engineer Week, Concord, NH, February 2018.

Martin Wosnik, Kaelin Chancey and Ian Gagnon will present on the Living Bridge Project at the Marine Energy Technology Symposium (part of Water Power Week) in Washington, DC:
Wosnik M; Chancey K; Gagnon I; Baldwin K; Bell E (2018) The “Living Bridge” Project: Tidal Energy Conversion at an Estuarine Bridge – Deployment and First Data, Proceedings of the 6th Marine Energy Technology Symposium, METS2018, April 30-May 2, 2018, Washington, DC.

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc):
UNH will need access protocols for the data closet at the bridge for maintenance of the data acquisition system.

UNH would like to repeat the load test again in April/May 2018 and will require the NHDOT approval and support for the load test.

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NHDOT needs to ask Eversource to install a power meter that can run in reverse, should the tidal turbine ever produce more power than the bridge and instrumentation can use. The maximum power output of the turbine at peak flow during spring tides was originally estimated at around 10 kW, but based on recent flow measurements could be as high as 15-20kW during short-duration “flow surges” during peak spring. This was requested by Eversource’s Distributed Generation Manager, Richard Labrecque, in a phone conversation with Martin Wosnik. R. Labrecque expressed Eversource’s support of the project in the conversation.

Anticipated research next 3 months:

Benchmark for Bridge Monitoring:
The integration of the structural health, mechanical operation and environmental instrumentation the sensors for remote access is complete. A trigger program has been established in March 2018 to trigger tentatively mechanical information. We are still working on this topic to directly control triggering a high-speed data collection from the operating control room at the bridge and plan to have this program in place by May/June 2018.

The validation of the structural models of the Memorial Bridge in Lusas® as well as local model of selected gusset-less connections at the Memorial Bridge with respect to collected data in Fall 2017. Calibration of the structural models for condition and performance assessment with respect to design verification.

Tidal Turbine Deployment System
The deployment of the tidal turbine deployment platform (TDP) with estuarine sensors at the Memorial Bridge occurred in June 2017. The TDP was move to the UNH Pier for installation of the pitch mechanism in late 2017. The installation of the tidal turbine on the deployment platform is planned for spring 2018, with power and communication connection to be installed in April 2018 by NEI.

The New Energy turbine is expected to be delivered in spring 2018. It will be mounted to TDP and then towed to the bridge. Commissioning and initial testing will then commence. UNH will then operate this particular turbine for the duration of approximately one year, provided operation and maintenance through the seasons prove feasible at reasonable effort and cost..

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Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.

As described in the "Progress this Quarter" section of this report, the schedule delay and increased cost related to the electrical conduit negatively impact this project.

Tasks (from Work Plan)	Planned % Complete	Actual % Complete
Living Bridge: Creating a Benchmark for Bridge Monitoring		
Project Coordination	**100**	**100**
Structural Model Creation	**100**	**95**
Design the instrumentation Plan	**100**	**100**
Sensor Deployment	**100**	**100**
Data Collection and Model Calibration	**90**	**80**
Trigger Protocol	**100**	**80**
Incorporation of collected data and model into NHDOT protocols	**0**	**0**
Final Report and Adoption Recommendation	**0**	**0**
Tidal Turbine Deployment Structure		
Deployment Structure Design	**100**	**100**
Project Permitting	**100**	**100**
Installation of Support Posts	**100**	**100**
Procurement of the Turbine deployment platform	**100**	**100**
Site Installation	**100**	**90**
Electrical Connection	**100**	**60**
Final Report and Poster	**0**	**0**